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Poel, Mike van der; Birkedal, Dan; Hvam, Jørn Märcher; Laemmlin, M.; Bimberg, D.

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Alpha parameter in quantum-dot amplifier under optical and electrical carrier modulation

M. van der Poel, D. Birkedal, and J. Hvam
Research Center COM, Technical University of Denmark, DK-2800 Lyngby, Denmark
M. Laemmlin and D. Bimberg
Institut für Festkörperphysik, Technische Universität Berlin, Germany

Abstract: Alpha parameter of a long-wavelength quantum-dot amplifier near 1.3 μm is measured to be below one even with saturated gain. A simple model explains difference in apparent alpha parameter under optical and electrical carrier modulation.

OCIS codes: (230.0250) Optoelectronics; (250.5980) Semiconductor optical amplifiers

1. Introduction

Strongly confined self-organized InAs/InGaAs quantum dots (QD) with ground state transitions approaching 1.3 μm are becoming available as an interesting candidate for active material in telecommunications components [1]. Among other things QD are attractive because of their alpha parameter, $\alpha = -4\pi / \lambda (dn/dN)(dg/dN)^{-1}$, expected to be low [2]. We measure alpha parameter of such a long-wavelength QD semiconductor optical amplifier (SOA) dots under optical and electrical carrier modulation.

2. Experiment

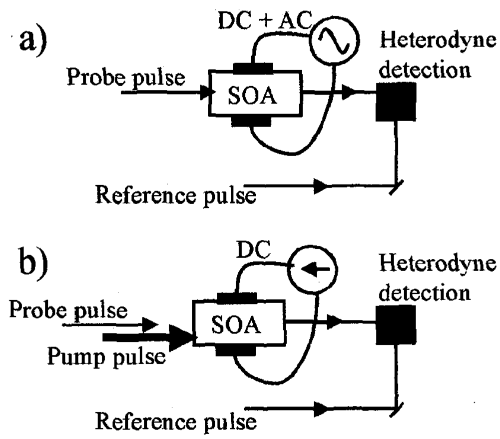

Fig. 1. Schematic of experimental setup showing principle of electrical (a) and optical (b) carrier density modulation.

The alpha parameter of a QD ridge waveguide (length 2 mm, width 7 μm) amplifier is measured by modulating carrier density electrically or optically. In the electrical case a small AC current at 1 MHz or 10 Hz modulates a DC bias current (fig 1a). The magnitude of the alpha parameter is extracted by heterodyne detection of a weak probe beam.

Gain and index changes of a probe pulse following a pump pulse are measured in a degenerate heterodyne pump-probe setup (fig 1b). Below (above) transparency the pump pulse injects (removes) carriers from the active layer. The resultant changes in probe pulse gain and phase correspond to an effective alpha parameter changing as function of delay time.

3. Results

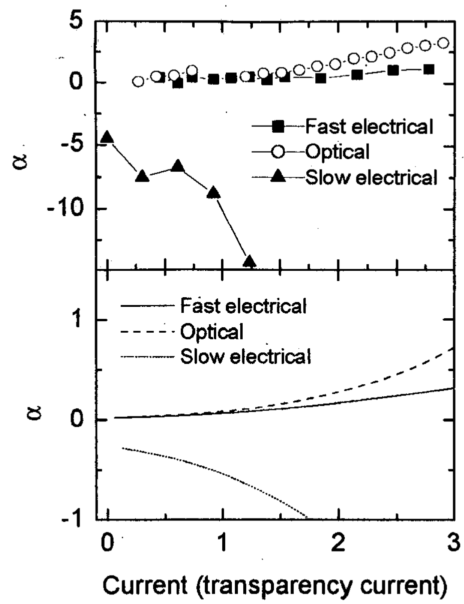

Fig. 2. Experimental (upper panel) and calculated (lower panel) alpha parameters for QD SOA under electrical and optical carrier modulation. Experimental data was taken at SOA peak gain (λ = 1246 nm) where transparency current density was 120 A/cm^2.

Alpha parameter values monotonically increase from about 0.2 to 1.2 and 3.3 in the fast electrical and optical cases respectively as bias current is increased from zero to 3 times transparency current (fig. 2). In the optical case pump-probe delay was fixed at 20 ps. The slow electrical case results in a large negative alpha parameter decreasing from −5 to −30. We also measure the evolution of the dynamical alpha parameter, as pump-probe delay is increased (fig. 3).

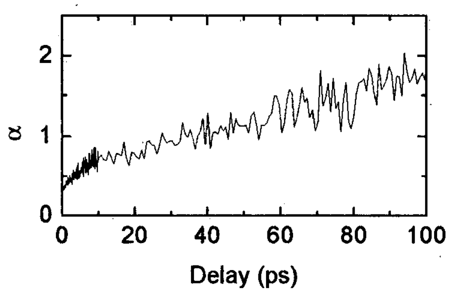

Fig. 3. Dynamic alpha parameter at zero bias.

4. Discussion and conclusion

A simple model characterizing the active layer by an ensemble of dot states narrowly centered on the probe frequency and a distant wetting layer with a constant density of states was made to understand salient features of the measurement (fig. 2). The intrinsic alpha parameter is measured with the fast electrical carrier modulation where waveguide temperature is constant during modulation. In contrast, amplifier temperature at gain decreases about 1 K in the presence of the strong pump increasing the apparent alpha parameter during optical carrier modulation.

Temperature variations during the slow current modulation give the large negative alpha parameter. These explanations are consistent with an independent determination of waveguide temperature derived from pulse propagation times through the amplifier. Notice that our simple model cannot accurately explain the size of the alpha parameter and understanding the evolution of the dynamical alpha parameter in fig. 3 is beyond the scope of this paper.

5. References

[1] A.R. Kovsh *et al.*, "InAs/InGaAs/GaAs quantum dot lasers of 1.3 mm range with enhanced optical gain", J. Crystal Growth **250**, 729 (2003)

[2] M. Willatzen, T. Tanaka, Y. Arakawa, J. Singh, "Polarization Dependence of Optoelectronic Properties in Quantum Dots and Quantum Wires", IEEE J. Quant. Electron. **30,** 640 (1994).